CALCULATION OF DIRECT DOSE FROM TA-18

Purpose

This Air Quality procedure describes the steps to make appropriate assumptions and calculate the direct external-radiation dose equivalent from operations at TA-18 (Los Alamos Critical Assembly Facility).

Scope

This procedure applies to the calculation and reporting of the dose equivalent to the public resulting from direct exposure to external radiation from the TA-18 site and reported as required by DOE Order 5400.1 and 5400.5.

In this procedure

This procedure addresses the following major topics:

Hazard Control Plan

The hazard evaluation associated with this work is documented in HCP-ESH-17-Office Work.

Signatures

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03/14/01

General information about this procedure

Attachments

This procedure has the following attachments:

Number	Attachment Title	No. of pages
1	TA-18 Operations for 1999	1
2	TA-18 Dose Estimate for 1999	1
3	Memo ESH-17:00-322 “Environmental Neutron Monitoring”	5

History of revision

This table lists the revision history and effective dates of this procedure.

Revision	Date	Description Of Changes
0	3/10/98	New document.
1	12/16/98	Add explanation of interpolation equation as an attachment and clarifying text in procedure. Correct errors in references to Attachments.
2	9/26/00	Use actual neutron measurements instead of a calculation.
3	3/13/01	Quick-change revision to correct typographical error to one number on p. 5 step 4 and Attachment 2 step 5.

Who requires training to this procedure?

The following personnel require training before implementing this procedure:

- ESH-17 employee assigned to calculate dose equivalent from operations at TA-18

Personnel previously trained to revision 2 do not require re-training to this revision.

Training method

The training method for this procedure is **self-study** (**reading**) and is documented in accordance with the procedure for training (ESH-17-024).

Definitions specific to this procedure

None.

General information, continued

References

The following documents are referenced in this procedure:

- NCRP Report No. 49
- ESH-17-024, "Personnel Training"
- ESH-17-506, "Calculation of air activation activity from TA-18", Mike McNaughton, 3/9/2000
- Memo ESH-4-MTS-97:038, "Calculation of External Radiation Dose to Members of the Public from Operations at TA-18", Tom Buhl to Dennis Armstrong, May 5, 1997
- LA-UR-98-2283, "Methodology for determining the dose to a member of the public from TA-18 operations", Anne White, Thomas Buhl, Dennis Armstrong, and William Casson, June 1998
- Memo ESH-17:00-048, "Reasons for changing procedure ESH-17-505", Mike McNaughton, January 26, 2000
- Memo ESH-17:00-322, "Environmental neutron monitoring", Mike McNaughton, June 13, 2000

Note

Actions specified within this procedure, unless preceded with "should" or "may," are to be considered mandatory guidance (i.e., "shall").

Calculating the dose equivalent at TA-18

Assessment of the dose equivalent at TA-18

The dose equivalent at TA-18 is measured at several locations around the perimeter of the facility at the closest locations where public access is allowed.

DOE Order 5400.1 (Chapter II section 8c) and DOE Order 5400.5 (Chapter II section 1a and section 6b(3)(b)) say the calculations should be as realistic as possible. Since no public member is present 24 hours a day, 365 days a year, the calculation includes an occupancy factor of 1/16. This factor is adopted from NCRP Report No. 49, Table 4, page 65. The factor of 1/16 is said to be appropriate for "outside areas used only for pedestrians or vehicular traffic." This same occupancy factor is adopted for the parking lot outside TA-18 because the parking lot is not generally used by the public; in this respect, it differs from a typical hospital parking lot discussed in NCRP Report No. 49.

Revisions 0 and 1 of this procedure used the method originally described in the memo from Tom Buhl, ESH-4-MTS-97:038 and expanded in LA-UR-98-2283. This method was appropriate before dosimeters were installed around TA-18 to measure the actual dose equivalent. More detailed reasons for changing this procedure were described in memo ESH-17:00-048.

Revision 2 of this procedure uses the direct measurements of the neutron dose equivalent provided by the albedo dosimeters around TA-18, as described in memo ESH-17:00-322 (Attachment 3).

The albedo dosimeter data are sent by the MTS team of ESH-4 to ESH-17 every quarter and are posted at http://www.air-quality.lanl.gov/Albedo-TLD.htm .

During some quarters, e.g. 98Q2, Pajarito Road is closed briefly for the duration of a special TA-18 operation, thus excluding the public. Data obtained when the public are excluded are not used to calculate the public dose. For this purpose, two dosimeters are deployed at each station; one remains in place continuously, the second is in place only when the road is open. If the road was closed, the dosimeters are distinguished by the words "continuous" and "road open." If the road was not closed during the year, every dosimeter is both "road open" and "continuous", and the two dosimeters at each location are averaged.

Calculating the dose equivalent at TA-18, continued

Assessment of the dose equivalent at TA-18

The annual dose equivalent to the maximally exposed individual (MEI) is the greater of:

(a) 1/16 of the largest annual dose equivalent at any of the monitoring stations, as recorded on "road open" dosimeters.

(b) the largest dose equivalent at an "open" location from a single operation.

Alternative (b) is important when there are a small number of operations. For the sake of argument, assume there is one operation. The MEI is the individual closest to TA-18 at this instant and in the worst case s/he receives the full dose.

As stated on page 3 of attachment 3, the gamma dose is 5% of the neutron dose equivalent. Therefore, in step 6 of the procedure below, the neutron dose is multiplied by 1.05 to obtain the total dose.

Use the following steps to calculate the annual dose equivalent to the maximally-exposed individual (MEI).

Step	Action
1	Obtain from ESH-4 or the ESH-17 web site (http://www.air-quality.lanl.gov/Albedo-TLD.htm) a list of neutron dose equivalents for the monitoring period of interest.
2	Using only the "road open" dosimeters, select the location with the largest annual dose equivalent. Usually, this will be location #3, which is closest to Godiva. Calculate the best estimate of the annual road-open neutron dose equivalent at this location from DOE operations. Subtract background measurements as appropriate.
3	Multiply the dose equivalent by the occupancy factor of 1/16.
4	Obtain from the facility manager or appropriate principal investigator at TA-18 a list of the criticality events that occurred for the monitoring period of interest. This is the same list specified in step 1 of the procedure ESH-17-506. An example is included as attachment 1.
5	Calculate the largest neutron dose equivalent at a publicly-accessible location from a single operation while the road was open, using one of the following conversion factors obtained from attachment 3: • 1/45 mrem/^{o}C from Godiva at location #3 • 1/90 mrem/^{o}C from Godiva at location #7 • 700 mrem/(A.s) from SHEBA out of the pit • 10 mrem/(A.s) from SHEBA in the pit.
6	The annual dose equivalent to the maximally exposed individual of the public is the larger of the results from step 3 and step 5, multiplied by 1.05 to include the gamma contribution.

Records resulting from this procedure

Records

The below documents generated as a result of this procedure are to be submitted as records to the records coordinator **annually within two weeks after the time the annual environmental surveillance report is submitted** to DOE.

- Summary of all data used in calculations
- explanatory information
- final results obtained

TA-18 OPERATIONS FOR 1999

SHEBA						
Date	Road (open/closed)	Position	Experiment	Power (Amps)	Energy (Amp*sec)	Estimated fissions
4/1/99	Open	Out	Test	1.00E-08	9.60E-06	2.59E+13
4/5/99	Open	Out	Test	5.00E-08	1.24E-04	3.36E+14
4/6/99	Open	Out	Test	1.20E-07	8.97E-05	2.42E+14
4/8/99	Open	Out	Test	4.40E-07	7.13E-04	1.92E+15
4/9/99	Open	Out	Test	2.50E-07	4.22E-04	1.14E+15
6/28/99	Open	Out	Familiarize	8.00E-09	4.00E-06	1.08E+13
7/14/99	Open	In Pit	Practice		6.41E-02	1.73E+17
7/21/99	Open	In Pit	Practice		6.21E-02	1.68E+17
7/29/99	Open	In Pit	Practice		4.55E-02	1.23E+17
8/5/99	Open	Out	P Recoil		2.00E-04	5.40E+14
8/25/99	Open	In Pit	Free Run		5.53E-02	1.49E+17
12/31/99	Open	Out	Dosimetry		1.73E-03	4.66E+15
Total						6.21E+17
GODIVA						
Date	Road	Position	Experiment	Type	Temp rise deg. C	Estimated fissions
3/19/99	Open	2	70° Burst	Burst	67.4	1.25E+16
3/23/99	Open	2	70° Burst	Burst	68.8	1.27E+16
3/24/99	Open	2	70° Burst	Burst	72.2	1.34E+16
4/1/99	Open	2	Test	Burst	71.2	1.32E+16
4/2/99	Open	2	Test	Burst	70.1	1.30E+16
4/7/99	Open	2	Dosimetry	Burst	114.3	2.12E+16
4/9/99	Open	2		Burst	60.5	1.12E+16
7/9/99	Open	2		Burst	65.4	1.21E+16
7/22/99	Open	2	Class	Free Run	82.0	1.52E+16
8/20/99	Open	2		Burst	101.6	1.88E+16
9/8/99	Open	2	Dosimetry	Burst	105.3	1.95E+16
9/15/99	Open	2	Dosimetry	Burst	100.0	1.85E+16
9/29/99	Open	2	Dosimetry	Burst	101.9	1.89E+16
10/21/99	Open	2	Radiation Damage	Burst	105.4	1.95E+16
Total						2.20E+17

TA-18 DOSE ESTIMATE FOR 1999

Step 1: The following data are from the www or the Environmental Surveillance Report.

ID#	Location	Dosimeter #1 (mrem)	Dosimeter #2 (mrem)
1	NEWNET Kappa Site	10.2	11.0
2	TA-36 Entrance	16.4	10.6
3	TA-18 Parking Lot	36.5	31.3
4	P2 Booster TA-54 Entrance	8.5	6.6
5	TA-51 Entrance	5.0	3.3
6	Hill NW of TA-18 Entrance	9.9	10.8
7	TA-18 Entrance at Pajarito Road	17.0	16.0
8.1	TA-49 Background	3.9	NA[a]
8.2	Santa Fe Background	3.9	NA[a]
9	Vault Control	1.2	NA[a]

Step 2: The maximum annual dose is at location #3.
Pajarito Road was not closed during 1999 so both dosimeters are "road open" dosimeters.
Average neutron dose equivalent at location #3 = 33.9 mrem.
Average background dose equivalent at locations #8 = 3.9 mrem.
Net dose from DOE operations = 30.0 mrem.

Step 3: Neutron dose equivalent to MEI = 30/16 = **1.9 mrem**.

Step 4: the list is in attachment 1.

Step 5: Maximum temperature rise in Godiva, ΔT = 114.3 °C.
Therefore, maximum dose equivalent from Godiva = 114.3/45 = **2.5 mrem**.
Maximum A.s from SHEBA out of pit = 1.73E-3 A.s
Therefore, maximum dose equivalent from SHEBA out of pit = 1.73E-3 * 700 = **1.2 mrem**.
Maximum A.s from SHEBA in pit = 6.41E-2 A.s
Therefore, maximum dose equivalent from SHEBA in pit = 6.41E-2 * 10 = **0.6 mrem**.
The largest neutron dose equivalent at a public location from a single operation is **2.5 mrem**.

Step 6: the largest result from steps 3 and 5 is 2.5 mrem.
The MEI annual dose equivalent is 1.05*2.5 = **2.6 mrem**.

To Robert Devine, ESH-4, G761
Thru Doug Stavert, ESH-17 Group Leader
Thru Joe Graf, Radiological Protection Program Manager
From Mike McNaughton
Symbol ESH-17:00-322
Date June 13, 2000

Environmental Neutron Monitoring

Summary

ESH-17 will standardize on the following method for monitoring environmental neutrons at Los Alamos National Lab. (LANL) and calculating the public dose.

- Use the LANL-standard 8823 albedo dosimeter, mounted on a 4-inch-thick slab of lucite, calibrated with the DOELAP-standard D2O-moderated Cf-252 source.
- Use the occupancy factors recommended in Table 4 (page 65) of NCRP Report No. 49: 1/16 for Pajarito Road and the TA-18 parking lot; 1 for all residences and work areas.

Discussion

At present, environmental neutrons are monitored at TA-3, -18, and -53 by ESH-1, -4, and -17. These measurements use LANL 8823 albedo dosimeters mounted on hydrogenous material. The dose equivalent is derived using a neutron correction factor, NCF, which corrects for the biological response of the human body relative to the physical response of the dosimeter.

The 8823 dosimeter is calibrated using DOELAP standard neutron sources consisting of a Cf-252 source, either bare or inside CH_2 or D_2O moderators up to a radius of 6 inches. The resulting NCF ranges from 1.08 for the bare source to 0.145 for the source inside a 5-inch-radius D_2O moderator. The hydrogen-moderated spectra have been used for personnel dosimetry and for environmental neutrons at TA-53, whereas a special NCF value of 0.07 has been used for environmental neutrons at TA-18. For environmental monitoring, we propose to standardize on the D_2O-moderated spectrum, for which the NCF = 0.145.

This estimate of the NCF is conservative, based on a combination of calculations and measurements, as follows.

Calculations

In an attempt to understand the NCF, I calculated the environmental neutron spectrum for a variety of conditions using the computer program MCNP. These calculations show that environmental neutrons differ significantly from the hydrogen-moderated neutrons used to calibrate personnel dosimeters.

Hydrogen-moderated spectra consist of three regions:
a) a fast-neutron peak, near 2 MeV;
b) a continuum of intermediate-energy neutrons; and
c) a thermal-neutron peak near 0.025 eV.

The fast neutrons are unscattered. Once a neutron scatters from hydrogen it changes direction and loses energy thus increasing its chances of scattering again. The intermediate-energy neutrons have scattered typically between 1 and 20 times and are in the process of being thermalized. The thermal neutrons have typically scattered more than 20 times.

In contrast to hydrogen-moderated neutrons, environmental neutrons are moderated by higher-Z materials such as nitrogen (in air) and silicon (in the earth). The mean-free path in air is 100 m, so there are very few unscattered (fast) neutrons in the publicly-accessible environment near LANL facilities.

The energy lost during each scatter from high-Z materials is small so the progress from high energy to thermal requires hundreds of scatters. Therefore, a typical environmental spectrum consists of a peak of intermediate-energy neutrons that decreases in energy as the distance from the source increases. In this respect, it is comparable to a D_2O-moderated spectrum. The similarity would be closer if the D_2O were replaced by a material with higher Z, and if the D_2O were thicker than 6 inches so as to provide a larger number of mean-free paths.

However, the DOELAP-standard D_2O-moderated spectrum is a better approximation to environmental neutrons than the CH2-moderated spectra.

Bonner-sphere measurements

William Casson reported measurements using Bonner spheres of the environmental neutron spectra from Godiva and SHEBA; see the memos: ESH-4-MTS-98:021 (March 17, 1998); and NIS6:99-172 (June 24, 1999). The results are consistent with the calculations discussed in the last section. These memos recommended the value of 0.07 for the NCF that has been used since 1997.

Other measurements, however, suggest a larger value of the NCF, as follows.

Measurements of the neutron dose equivalent from SHEBA

Tom Buhl reported measurements of neutrons from SHEBA in the memo HSE8-85-1424-1 (March 15, 1985). The largest reported dose rates at Pajarito Road were obtained near the water tanks at the entrance to TA-54: 37 mrem/h was measured with a RASCAL-BF3 detector, and 26 mrem/h was measured with a TLD-600; both of these were inside 9-inch-diameter-CH2 spheres. These dose rates were obtained while SHEBA was operating at 1 kW; according to NIS6-SHEBA-OA-6, 1 kW corresponds to 1.3E-5 A on the RAP2 ion-chamber detector. From these

numbers, the number of Amp-seconds on the RAP2 can be converted to the dose equivalent at Pajarito Road:

- Using a RASCAL, the conversion factor = 1.3E-3 A.s/mrem;
- Using a TLD-600, the conversion factor = 1.8E-3 A.s/mrem.

A similar number is derived from the memo ESH-4-MTS-97:053 from William Casson (June 20, 1997): 3.5 mrem/h was measured with a PNR-4 while SHEBA was operating at 1.5E-6 A, which yields the result:

- Using a PNR-4, the conversion factor = 1.5E-3 A.s/mrem.

Tom Buhl et al. measured the dose equivalent from SHEBA using two WENDI detectors on December 13, 1999, near the water tanks at the entrance from Pajarito Road to TA-54. The detectors registered 1.8 mrem while the RAP registered 1.73E-3 A.s, so

- Using WENDIs, the conversion factor = 1.0E-3 A.s/mrem.

With these data, we can use the environmental albedo-dosimeter data to estimate the NCF. In the table below, the "Dosimeter" column is the 137Cs-equivalent value of element 8 minus element 7 of the 8823 dosimeter at the entrance to TA-54, corrected for background. The "Dose equivalent" is calculated from the "SHEBA emission" (A.s) using the average conversion factor: 1.4E-3 A.s/mrem. The NCF is the dose equivalent divided by the 137Cs-equivalent value.

year and quarter	SHEBA emission (A.s)	Dose equivalent (mrem)	Dosimeter E8-E7 (137Cs-equiv.)	NCF
99Q1	1.3E-3	0.9	4.3	0.21
99Q2	.86E-3	0.6	4.3	0.14
99Q3	2.2E-3	1.6	13	0.12
99Q4	1.7E-3	1.2	6.9	0.17
total	6.1E-3	4.4	28.5	0.15

MCNP calculations indicate that the neutron detectors mentioned above all overestimate the dose equivalent from intermediate energy neutrons, so the above estimates of the NCF are conservative. The average, NCF=0.15, is consistent with the value obtained from the D_2O moderated source, NCF=0.145.

Other useful information derived from the SHEBA measurements are:

the gamma dose is 5% of the neutron dose equivalent; and
the dose at the entrance to TA-18 is half that at the entrance to TA-54.

Measurements from Godiva

Tom Buhl reported measurements from Godiva in the memo HSE8-88-170 (March 15, 1988) and concluded that DeltaT = 120 degrees C results in 1 mrem at location #3, which is the closest location to Godiva, in the parking lot 115 m from Godiva.

William Casson reported Bonner-sphere measurements from Godiva in the memo ESH-4-MTS-97:053 (June 20, 1997) and concluded that DeltaT = 110 degrees C corresponded to 1 mrem at location #6, half way up the hill along Pajarito Road. From this result we estimate the conversion factors at location #3 both by using the inverse-square law and using the data obtained during the Godiva burst of October 29, 1997. Either method yields a conversion factor for Godiva at location #3: 45 C/mrem.

In the following table, the conversion factor 45 C/mrem is used to obtain an estimate of the NCF from Godiva. The dose equivalent is obtained by dividing DeltaT by the conversion factor: 45 C/mrem. The 137Cs-equivalent dosimeter value is element 8 minus element 7 of the 8823 dosimeter closest to Godiva, corrected for background. The NCF is the ratio of the dose equivalent to the 137Cs-equivalent value.

Year and quarter	Godiva DeltaT	Dose equiv. (mrem)	Dosimeter 137Cs-eq.	NCF
99Q1	525 C	11.7	83	0.14
99Q2	65 C	1.4	10	0.14
99Q3	491 C	10.9	94	0.12
99Q4	105 C	2.3	19	0.12
total	1186 C	26.4	206	0.13

These estimates are conservative. The average NCF = 0.13, is consistent with the value obtained from the D_2O-moderated neutron source: NCF = 0.145.

Implications for SHEBA

According to the TA-18 ALARA-implementation plan, NIS6:98-257, and the SHEBA operator aid, NIS6-SHEBA-OA-6 dated 5/3/2000, the following conversion factor are used for planning SHEBA operations:

3E-2 A.s/mrem at the railroad gate when SHEBA is in the pit;
4E-4 A.s/mrem at the railroad gate when SHEBA is out of the pit;
8.6E-4 A.s/mrem at Pajarito Road.

These conversion factors are more conservative than the conversion factors listed above, and therefore allow a margin of safety.

Implications for Godiva

The policy described in the NIS6 ALARA plans, NIS6-AP-1,R03 (July 17,1998) and NIS6:98-257 (July 16, 1998) requires approval of the NIS6 group leader for Godiva bursts if DeltaT > 140 degrees C, and closing Pajarito Road if DeltaT > 350 degrees C. This policy is consistent with the data discussed here.

However, a Godiva burst with DeltaT = 200 degrees C will register 5 mrem in the dosimeter at location #3 (closest to Godiva, in the parking lot). Therefore, a conservative policy would be to close the parking lot during a burst with DeltaT >200 degrees C.

Public Occupancy Factor

We propose to use an occupancy factor of 1/16 when calculating the public dose on Pajarito Road and the parking lot at the entrance to TA-18. This factor corresponds to the value in Table 4 (page 65) of NCRP Report No. 49, and is appropriate for "outside areas used only for pedestrians or vehicular traffic." An occupancy factor of 1 will continue to be used for work areas such as East Gate north of TA-53.

When planning an operation, we recommend planning to keep the dose on all dosimeters below 100 mrem/yr without applying an occupancy factor.

Most Exposed Individual

The following method will be used to calculate the dose to the most-exposed individual (MEI) member of the public for the Environmental Surveillance Report:

a. select the largest dose recorded by the dosimeters in publicly-accessible areas and multiply by the appropriate occupancy factor;
b. select the largest dose resulting from a single operation of one hour or less;
c. the dose to the MEI is the larger of a or b.

Conclusions

1. Estimates of the NCF for the 8823 albedo dosimeters range from about 0.05 to 0.15. ESH-17 will use the most conservative value, NCF = 0.145, which results from calibrating the dosimeters with the D_2O-moderated neutron spectrum.

2. In reporting the dose at Pajarito Road, Potrillo Road, or the parking lot at the entrance to TA-18, ESH-17 will use an occupancy factor of 1/16. However, when planning TA-18 operations, we recommend keeping the accumulated dosimeter readings below 100 mrem/yr without applying an occupancy factor.

3. Consideration should be given to closing the parking lot at the entrance to TA-18 when the Godiva DeltaT is expected to exceed 200 degrees C.